CHAPTER 9

PLANE-TABLE TOPOGRAPHY AND MAP PROJECTION

In the previous chapter, you studied the procedures used to perform topographic surveying using the transit-tape or transit-stadia methods. As you know, when either of these methods is used, a topographic map is prepared as a separate operation that uses the field notes from the survey to prepare the map. Another method used in topographic surveying and mapping is the plane-table method. This method is preferred by many surveyors since it combines the fieldwork and the office work into one operation that produces a completed, or nearly completed, map in the field. This chapter discusses the basic principles and procedures that you will use when performing plane-able topography.

Another topic discussed in this chapter is map projection. As you will learn, maps can be prepared using various projection methods to portray all or part of the earth's surface on the flat plane of a map or chart. As an EA, you will seldom use most of these methods in drawing maps. However, it is important that you understand the principles of map projection so that you will be able to read and interpret accurately the various types of maps that you will use when plotting control points for surveys or when plotting fire missions as a mortar platoon member in a construction battalion.

PLANE-TABLE TOPOGRAPHY

As mentioned above, the plane-table method of topographic surveying and mapping combines fieldwork (surveying) with office work (drafting) to produce a topographic map. This is so, because when you use plane-table equipment, topographic details are plotted directly on the map in the field. The plane-able method is advantageous in open country and when many irregular lines need to be plotted. It is also advantageous for small-scale mapping. There are, however, some disadvantages. For example, you are required to spend mom time in the field, more equipment (some awkward to handle) must be carried, and you will need mom time to become skilled in using the plane table. Other advantages and disadvantages of the plane-table method are discussed later in this chapter.

A plane-table field party for a large survey should consist of an instrumentman, a note keeper or computer, and one or more rodmen. The instrumentman operates the plane table and alidade, makes the observations, and performs the plotting and sketching. The note keeper reduces stadia readings to horizontal and vertical distances and computes the ground elevations for rod observations. He also carries and positions an umbrella to shade the plane table. The rodman carries a stadia board or Philadelphia rod and holds it vertically at detail points and critical terrain features.

Chapter 11 of the EA3 TRAMAN describes the plane-table equipment and uses. That discussion includes the procedures used to setup and level a plane table and a description of various types of alidades. For plane-table topography, a telescopic alidade, rather than an open-sight alidade, is preferred. Before proceeding further in this chapter, it is strongly recommended that you review pages 11-33 through 11-35 of the EA3 TRAMAN.

LOCATING DETAILS BY PLANE TABLE

We will briefly explain the use of the plane table as follows. Take into the field a sheet of plane-table paper of suitable size and which has the control traverse (fig. 9-1) already plotted to suitable scale. Naturally, you use the same scale as the control traverse to lay off horizontal distances on the map.

Attach the paper to the table. Then set up and carefully level the table so that D_1 on the paper is directly over D_1 on the ground. In this example, D_1 *is* a point of known elevation (532.4 feet). Now the table must be oriented before any detail points can be located. In other words, the table has to be rotated or turned so that the points plotted on the plane-table sheet are in relationship to the corresponding points on the ground. So, with the edge of the alidade blade on D_1 and the telescope trained on *A,* orient the table by rotating it to bring D_1A on the paper in line with the

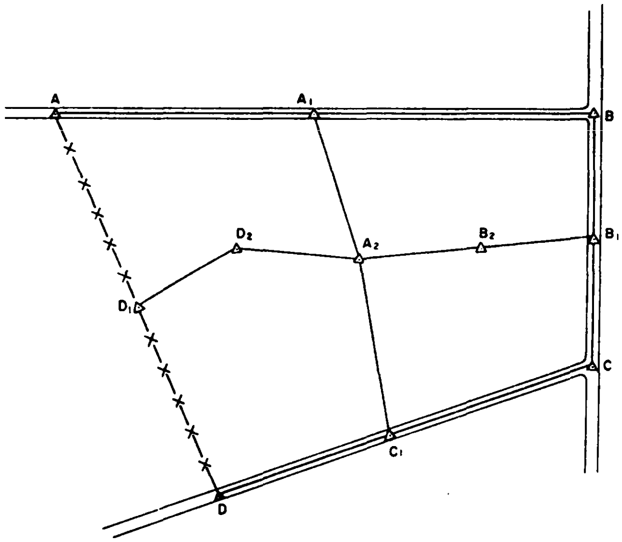

Figure 9-1.—Primary traverse and secondary traverse.

edge of the blade. A more in-depth discussion of orienting the plane table will follow later in this chapter.

Next, carefully measure the vertical distance between the horizontal line of sight through the telescope and the ground level at D_1. Let's say this distance is 4.5 feet. This means that, whenever you sight on a rod, you will line up the horizontal cross hair with the 4.5-foot graduation on the rod.

Figure 9-2 is a sketch of the detail points that we are plotting. Point D_1 and point A in this figure correspond to the same points in figure 9-1. Assuming that your alidade is equipped with a Beaman stadia arc (some alidades are not), plot point 1 of figure 9-2 in the following way. With the edge of the alidade blade exactly on D_1 on the paper, train the telescope on a rod held on point 1, and line up the horizontal cross hair with the 4.5-foot mark on the rod.

You read a rod intercept of 6.23 feet. This means the slope distance is 623.0 feet. On the H-scale of the Beaman arc, you read three-tenths of one percent; you will have to estimate this less than one-percent reading. The horizontal distance, then, is three-tenths of one-percent less than the slope distance, or

623.0 feet - (623.0 x 0.003 feet) = 623.0-1.87.

This rounds off to the nearest foot at 621 feet. Add a focal distance of 1 foot, and the result is 622 feet.

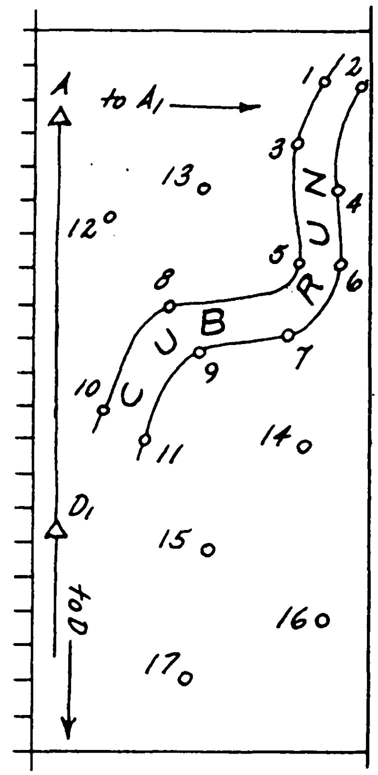

Figure 9-2.-Sketch of topographic detail points.

On the V-scale, you read 44. You know that the value you use is the difference between what you read and 50. In this case, it is 6. Therefore, the difference in elevation is 6 percent of the slope distance, or

623.0 x 0.06 = 37.4 feet.

Then, the elevation of point 1 is the elevation of D_1 minus the difference in elevation, or

532.4 -37.4 = 495.0 feet.

As you know, the difference in elevation was subtracted because the vertical angle was negative.

Finally, with the edge of your alidade blade still on D_1 and your telescope still trained on point 1, you can draw a light line and measure off 622 feet from D_1 along the line to locate point 1. At that distance along the line, mark and label the point and write in the elevation. Many topographers use the decimal point in the elevation to mark the point.

ORIENTATION METHODS

As you learned from the above example, plotting of detail points cannot begin until the plane-table drawing board or table is oriented. Orientation consists of rotating the leveled table around its vertical axis until the plotted information is in exactly the same relationship as the data on the ground. There are several methods of orienting the plane table. Some of these methods are discussed below.

Backlighting

The usual method of orienting the plane table is by backlighting. Using this method, you orient the board by backlighting along an established line for which the direction has previously been plotted. Figure 9-3 illustrates this method.

In figure 9-3, points *a* and *b* are the previously plotted locations of points *A* and *B* on the ground. First, you set up and level the table at point *B*. Then you place the straightedge of the alidade along line *ba* and rotate the table until the alidade is sighted on point *A*. Once the alidade is sighted on *A*, the table is clamped and the orientation is checked by sighting on another visible and previously plotted point. The direction to any other visible point can be plotted as a ray from the plotted position of the occupied station.

Orientation by Compass

For rough mapping at a small scale, you can use a magnetic compass to orient the plane table. If the compass is fixed to the table, you orient by rotating the table about its vertical axis until the established bearing (usually magnetic north) is observed. If the compass is attached to the alidade, you first place the straightedge along a previously drawn line that represents a north-south line. The table is then oriented by rotating it until the compass needle points north.

As you should recall from your study of the EA3 TRAMAN, you know that the earth's magnetic field and local attraction will greatly affect the pointing of the compass needle. For these reasons, you should avoid using the compass to orient the plane table when orientation by backlighting can be accomplished.

Resection

Orienting a plane table by backlighting or by compass requires occupying a station whose position has been plotted. Resection, however, enables you to orient the plane table without setting up at a previously plotted station. This technique uses two or more visible points whose positions are plotted on the plane table. From these plotted points, rays are drawn back toward the occupied but unplotted point.

TWO-POINT METHOD.— The two-point method of resection is used to orient the plane table and establish the position of a station when two previously plotted points cannot be occupied. A description of the two-point method is as follows:

In figure 9-4, *A* and *B* are visible, but inaccessible, control points. Points *a* and *b are* the plotted positions of *A* and *B*. The location of unplotted point C is approximately estimated and marked *c'*. *D* is a selected

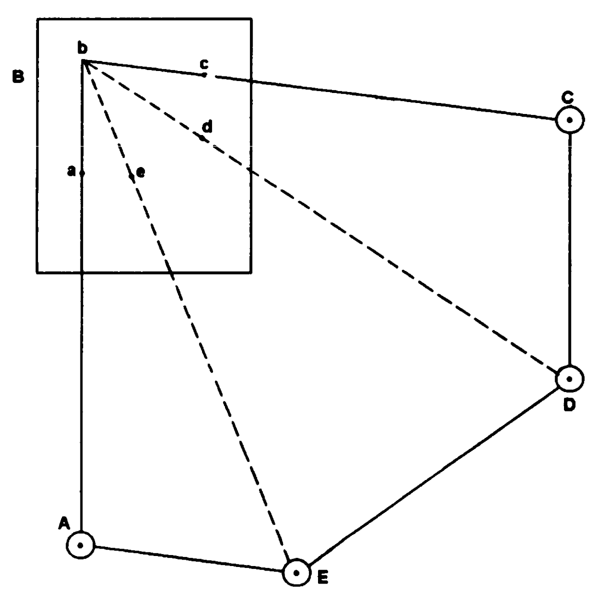

Figure 9-3.-Orientation by backlighting.

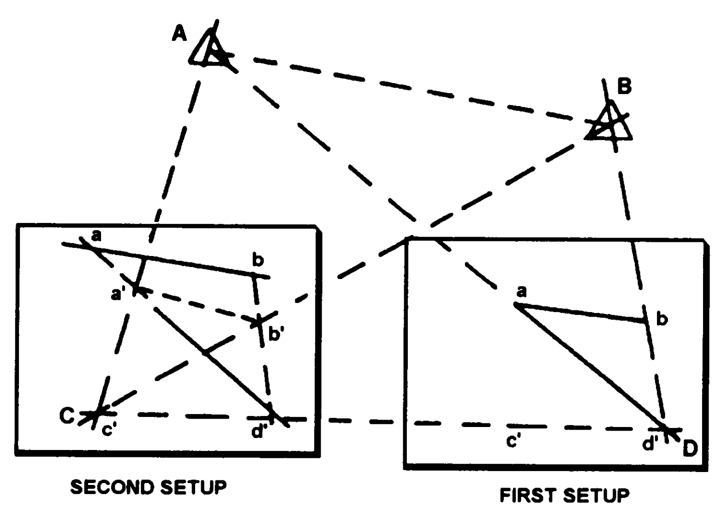

Figure 9-4.—Two-point method of resection.

and marked point when rays from A and B will give a strong intersection (angle *ADB is* greater than 300).

First set up and level the plane table at point D (first setup, fig. 9-4). Using plotted points a and b, draw resection rays from A and B. *These* rays intersect at d' which is the tentative position of D. Draw a ray from d' toward C. Plot c' on this line at the estimated distance from D to C.

Next, set up the plane table at C (second setup, fig. 9-4) and orient by backlighting on D. Sight on A and draw a ray through c' intersecting line ad' at a'. In a like manner, sight on B to establish b'. You now have a quadrilateral $a'b'd'c'$ that is similar to $ABDC$. Since, in these similar quadrilaterals, line $a'b'$ should always be parallel to line AB, the error in orientation is indicated by the angle between ab and $a'b'$.

To correct the orientation, place the alidade on line $a'b'$ and sight on a distinctive distant point. Then move the alidade to line ab and rotate the table to sight on the same distant point. The plane table is now oriented, and resection lines from A and B through a and b plot the position of point C.

THREE-POINT METHOD.— The three-point method involves orienting the plane table and plotting a station when three known plotted stations can be seen but not conveniently occupied.

Set up the plane table at the unknown point P (fig. 9-5) and approximately orient the table by eye or compass. Draw rays to the known points A, B, and C. The point ab denotes the intersection of the ray to A with the ray to B. Points bc and ac *are* similar in their notation. If the plane table is oriented properly, the three rays will intersect at a single point. Usually, however, the first orientation is not accurate, and the rays intersect at three points *(ab, bc,* and *ac)* forming a triangle, known as the triangle of error.

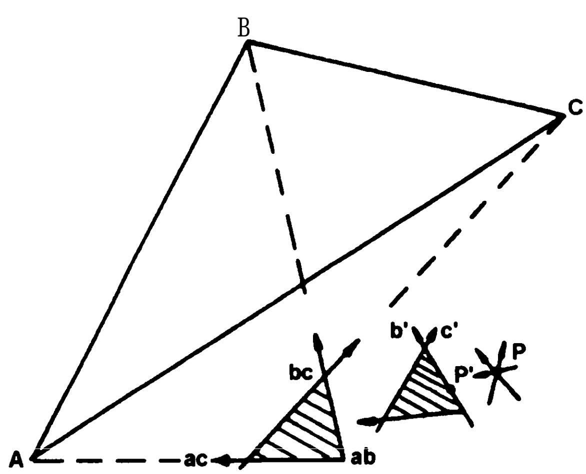

Figure 9-5.—Three-point method of resection.

From the geometry involved, the location of the desired point, P, must fulfill the following three conditions with respect to the triangle:

1. It will fall to the same side of all three rays; that is, either to the right or to the left of all three rays.

2. It will be proportionately as far from each ray as the distance from the triangle to the respective plotted point.

3. It will be inside the triangle of error if the triangle of error is inside of the main plotted triangle and outside the triangle of error if it is outside the main triangle.

In figure 9-5, notice that the triangle of error is outside the main triangle, and almost twice as far from B as from A, and about equally as far from C as from B. The desired point, P, must be about equidistant from the rays to B, and to C, and about one half as far from the ray to A, and the three measurements must be made to the same side of the respective rays. As drawn, only one location will fulfill all these conditions and that is near P'. This is assumed as the desired location.

The plane table is reoriented using P' and backlighting on one of the farther points *(B). The* new rays (a', b', and c') are drawn. Another (smaller) triangle of error results. This means that the selected position, P', was not quite far enough. Another point, P, is selected using the above conditions, the table is reoriented, and the new rays are drawn. If the tri- angle had become larger, a mistake was made and the selected point was on the wrong side of one of the rays. The directions should be rechecked and the point reselected in the proper direction.

The new point, P, shows no triangle of error when the rays are drawn. It can be assumed to be the desired location of the point over which the plane table is set. In addition, the orientation is correct. Using a fourth known and plotted point as a check, a ray drawn from that point should also pass through P. If not, an error has been made and the process must be repeated.

Normally the second or third try should bring the triangle of error down to a point. If, after the third try, the triangle has not decreased to a point, you should draw a circular arc through one set of intersections *(ab,* $a'b'$) and another arc through either of the other sets *(bc,* $b'c'$, or *ac,* $a'c'$). *The* intersections of the two arcs will locate the desired point, *P*. This intersection is used to orient the plane table. A check on a fourth location will prove the location.

TRACING-CLOTH METHOD.— Another method you can use to plot the location of an unknown point from three known points is the tracing-cloth method of resection. Figure 9-6 illustrates this method.

In the figure, points *a, b,* and c are the plotted positions of three corresponding known stations *(A, B,* and *C). P* is the point of unknown location over which the plane table is set. To plot the location of *P* you first place a piece of tracing paper (or clear plastic) over the map and select any convenient point on the paper as ***P′***. Then you draw rays from ***P′*** toward the three known stations. Next, you loosen the tracing paper and shift it until the three rays pass through the corresponding plotted points *a, b,* and *c.* The intersection of the rays marks the location of *P,* which can be pricked through the tracing paper to locate the point on the map.

POINT LOCATION

The horizontal location of points can be determined by triangulation using the plane table. Any two points plotted on the plane-table sheet can act as a base for triangulation. A ray drawn from each of these points to some unknown point will form a triangle, with the distance between the two known

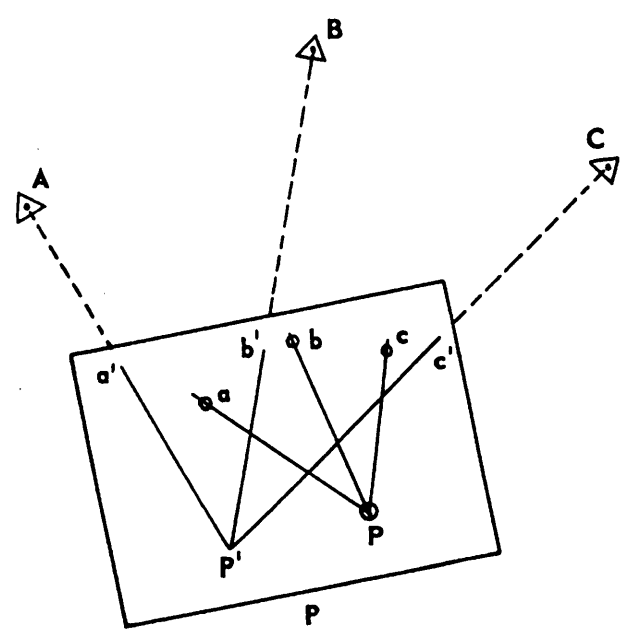

Figure 9-6.-Tracing-cloth method of resection.

plotted points as the third side. The newly plotted position of the third point will be at the intersection of the rays. The rays to the unknown point maybe drawn while occupying the known stations. This is called intersection. The rays also may be drawn while occupying the unknown point, and this is known as resection.

Resection

The methods of resection were explained in the discussion of plane-table orientation. As you know, when using resection methods it is unnecessary to occupy known stations. While resection can be used with two known points, you should use mom than two points to determine the location of a point to a higher degree of precision.

Intersection

Intersection is accomplished by setting up and orienting the plane table at each of two or more known stations in turn. At each station, the alidade is pointed toward the unknown point, and a ray is drawn from the plotted position of the occupied station toward the point being plotted. As such rays are drawn from two or more stations, their point of intersection is the plotted position of the required station. Two points are the minimum requirement to establish a location. For more accuracy, however, you should occupy three or more points.

Radiation

In plane-table surveys when intersection is used, a series of radiating rays are drawn and marked. These rays all radiate from known stations. Points are located by drawing rays from one or more known stations. The intersection of the rays determines the plotted location of the desired points. When drawing rays, be sure to identify clearly the object that each ray is being drawn to. This is important since an object viewed from one direction may appear differently when viewed from another direction. This can lead to rays being drawn to the wrong object which will result in errors in plotting point locations.

Progression

Progression, or plane-table traverse, starts from a known position and uses a continuous series of direction and distances to establish positions. This method of point location is illustrated in figure 9-7.

After you set up and orient the plane table at the first station, you draw the direction to the next point on the survey with a radiating ray. The distance between the occupied station and the new point is measured and plotted along the ray. The new plotted position is now considered a known position and can be occupied and used as the next station on the line. The plane table is setup and oriented over this station and another radiating ray is drawn to the next point. This process continues for the length of the traverse.

Orientation plays an important role in plane-table traverse. Slight errors in direction at each setup can accumulate rapidly and become large in a short time. Long traverses should be avoided except in reconnaissance surveys.

VALUES OF PLANE-TABLE METHOD

Advantages of the plane-table method of topographic surveying are as follows:

1. The map is made directly in the field, thus combining the data collection and drafting into a single operation. The area under survey is visible as a whole, which tends to minimum the overlooking of important data. Errors in measurement maybe easily checked by taking check observations on a prominent point whose position has been plotted on the map. If the edge of the blade does not contact the proper point or points, an error is indicated. An error thus located can be easily corrected on the spot.

2. Since all computation and plotting is performed in the field, the keeping of field notes is not a mandatory requirement in plane-table topography; the decision is left up to your supervisor; however, plane-table field notes are useful as a training device. You should keep this in mind when, later in your career, you are training junior EAs in plane-table work.

3. The graphic solutions of the plane table are much quicker than the same solutions by methods requiring angular measurements, linear measurements, and computations. Thus a great deal more area can be covered in much less time.

4. When the country is open and level, the plane-table topographer has a wider choice in the selection of detail points. He need not be hampered by backsight-foresight requirements. He can locate inaccessible points easily by graphic triangulation or quickly determine the location of a point with reference to one, two, or three points of known location.

5. Irregular lines, such as streams, banks, and contours, can be sketched.

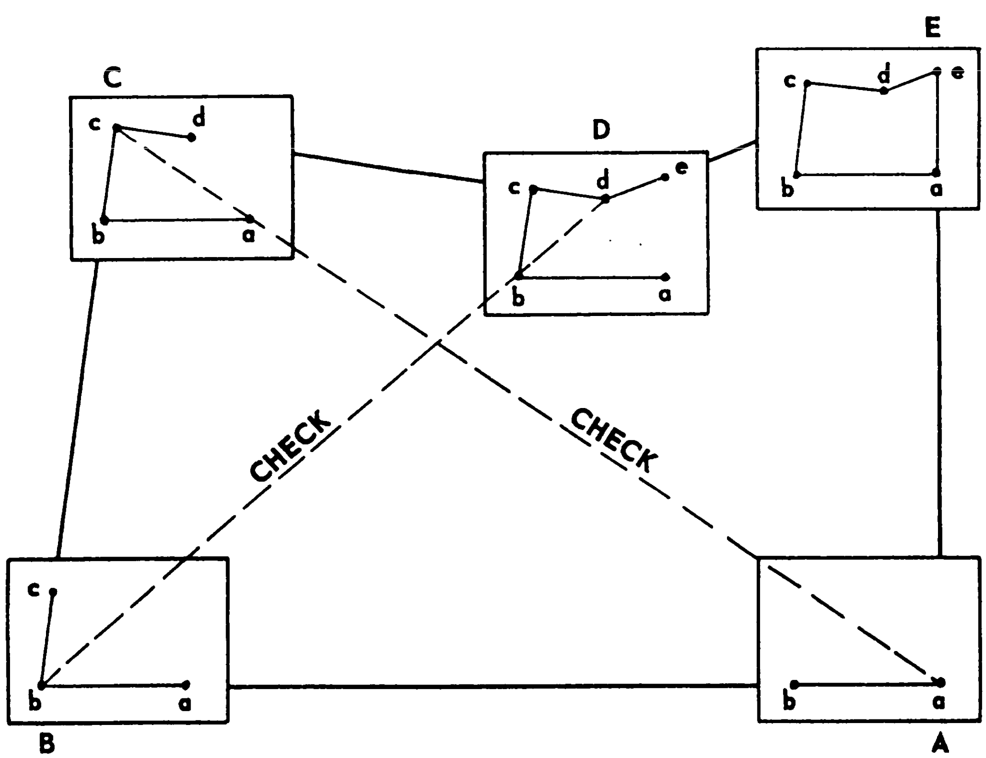

Figure 9-7.-Progression.

6. Fewer points are required for the same precision in locating contours (only 50 to 60 percent of the number on a comparable transit-stadia survey are required to locate contours with the same degree of accuracy).

Disadvantages of the plane table method are as follows:

1. The plane table and its plotting and drawing accessories are more difficult to transport than transit-stadia equipment.

2. Weather not bad enough to rule out transit-stadia will make plane-table work impossible.

3. The use of the plane table is limited to relatively level, open country. It is unsuitable for wooded country.

4. Control must be plotted in advance for precise work on the plane table.

As mentioned above, keeping field notes is not mandated for plane-table topographic work; however, when notes are kept, they should appear as shown in figure 9-8. An explanation of the columns shown in these notes is as follows:

1. OBJ: Self-explanatory.

2. ROD INT (S): Rod or stadia interval.

3. H-SCALE: Reading from the Beaman arc horizontal scale when the stadia interval was taken. (In this example, the stadia arc we are using is a horizontal scale subtraction type: vertical scale index = 50.)

4. CORRECT H DIST: Corrected horizontal distance. This distance is computed as explained in chapter 8 of this TRAMAN.

5. V-SCALE: Reading from the Beaman arc vertical scale when the middle cross hair was sighted on the rod and RC (column 7) was recorded. (Vertical scale index = 50.)

6. PRODUCT ±: Product difference; you compute this by subtracting 50 from the V-scale (column 5) and then multiplying this difference by the stadia interval (column 2). Indicating the correct sign, + or -, is very important.

7. RC: Rod reading when the vertical scale was read and the center cross hair was sighted on the rod. The RC is always negative because it is considered a foresight.

8. DE ±: Algebraic sum of columns 6 and 7.

9. HI: Height of instrument obtained by adding backsight reading to existing elevation.

10. ELEV: Computed elevation; algebraic sum of columns 8 and 9.

11. REMARKS: Self-explanatory.

When other types of alidades are used, you may find it necessary or advantageous to alter the format of your field notes. Remember, too, that before you use any instrument, including the alidade, you should always read and fully understand the operating instructions for the instrument.

1

PLANE-TABLE MAPPING
NORTH FIELD

OBJ.	ROD INT S	H-SCALE	CORRECT H DIST	V-SCALE	PRODUCT (+/-)
(1)	(2)	(3)	(4)	(5)	(6)
A					
1	6.25	0	625	55	+ 31.25
2	1.60	0	160	48	- 3.2
3	2.05	3	199	68	+ 36.9
4	3.75	2	368	62	+ 45.0
5	3.65	0		52	
6	0.85	1		58	

INST. - ALIDADE #1 — 14 AUG. 19__ — 2
- DOE — CLEAR, 70°F
- DOOR
- SMITH/JONES

RC	DE (+/-)	HI	ELEV	REMARKS
(7)	(8)	(9)	(10)	(11)
	+ 4.3	116.7	112.4	ELEV STA B
-4.6	+26.6		143.3	TOP OF SLOPE
-2.8	- 6.0		110.7	BOTTOM OF SLOPE
-8.4	+28.5		145.2	℄ ROAD
-7.2	+37.8		154.5	SPOT ELEV
-6.7				SPOT ELEV
-4.3				SPOT ELEV

Figure 9-8.-Plane-table notes.

PLANE-TABLE POINTERS

One of the troublesome problems in operating a plane table is the difficulty of keeping the alidade blade on the plotted position of the occupied point, such as P in figure 9-9. As the alidade is moved to sight a detail, the edge moves off point P. A solution sometimes tried is to use a pin at P and pivot around it, but a progressively larger hole is gouged in the paper with each sight. To eliminate this problem, use two triangles to draw a parallel line with the straightedge of the telescope over pivot point P. The small error produced by the eccentric sight is no greater than that resulting from not being exactly over the ground point, P, or even that caused by the telescope axis not being over the edge of the blade.

Other pointers that may be helpful concerning the use of the plane table are as follows:

1. Use buff or green detail paper to lessen the glare.

2. Plot and ink the traverse in advance of the detailing, showing lengths of traverse lines; coordinates of triangulation stations, if known; and useful signals

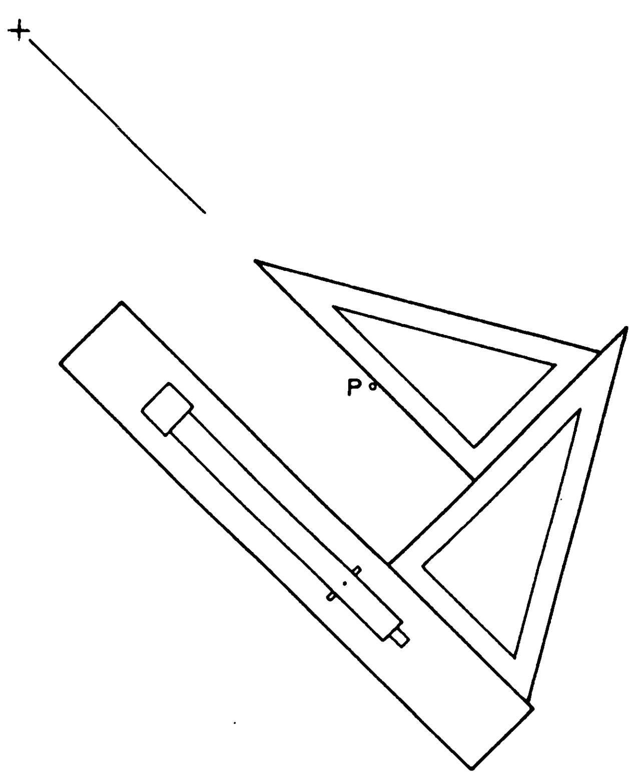

Figure 9-9.—Transfer of pivot point.

3. Have a least one vertical control for each three hubs of a traverse, and show all known elevations.

4. Cover the portion of the map not being used.

5. Setup the table slightly below elbow height.

6. Check the orientation on two or more lines if possible.

7. Check the distance and elevation difference in both directions when setting a new hub.

8. Read the distance first and then the vertical angle; or with a Beaman arc, read the H-scale and then the V-scale.

9. To keep the paper cleaner, lift the forward end of the alidade blade to pivot instead of sliding the blade.

10. Clean the paper frequently to remove graphite.

11. Check the location of hubs by resection and cutting in (sighting and plotting) prominent objects.

12. Draw short lines at the estimated distances on the map to plot points. Do not start the lines at the hub occupied.

13. Identify points by consecutive numbers or names as they are plotted.

14. Have the rodman make independent sketches on long shots for later transference to the plane-table map.

15. Use walkie-talkie sets to enable the rodmen to describe topographic features when the observer cannot identify them because of distance and obstacles.

16. Use the same points to locate details and contours whenever possible.

17. Sketch contours after three points have been plotted. Points on the maps lose their value if they cannot be identified on the ground.

18. Show spot elevations for summits, sags, bridges, road crossings, and all other critical points.

19. Tie a piece of colored cloth on the stadia rod at the required rod reading to speed work in locating contours by the direct method.

20. Use vertical aerial photographs for plane-table sheets. The planimetric details can be checked and contours added.

21. Use a 6H or harder pencil to avoid smudging.

Sources of Error in Plane-Table Work

Sources of error in plane-table operation include the following conditions or procedures:

1. Table not level
2. Orientation disturbed during detailing
3. Sights too long for accurate sketching
4. Poor control
5. Traversing and detailing simultaneously
6. Too few points taken for good sketching

Mistakes in Plane-Table Work

Some typical mistakes made in plane-table work are as follows:

1. Detailing without proper control
2. Table not level
3. Orientation incorrect

DEVELOPMENT OF A TOPOGRAPHIC MAP

In this final section on topography, we will discuss the typical steps leading to the production of a topographic map. In this discussion, you should notice the different operations that are commonly involved and how those operations interplay with one another.

In developing a topographic map, you should first gather all available maps, plans, survey data, and utilities data that pertain to the site and study them carefully. Consider the boundaries of the site in relation to the intended use of the topo map. If the map is to be used for design purposes, certain off-site information will be even more important than on-site details; for example, the location and elevations of utilities and nearby streets are vital. The location of drainage divides above the site and details of outfall swales and ditches below the site are necessary for the design of the storm drainage facilities. Topographic details of an off-site strip of land all around the proposed limits of construction are necessary so that grading can be designed to blend with adjacent areas. Decide what datum and bench marks are to be used; consider previous local surveys, U.S. Coast and Geodetic Survey (USC&GS) monuments, sanitary sewer inverts (not rims—they are frequently adjusted), and assumed datum. Determine whether there is a coordinate system in the area monumented sufficiently for your use; if not, plan to use assumed coordinates. In the latter case, decide on the source of the meridian: adjacent surveys, magnetic, assumed, or shooting the Sun or Polaris (discussed at the EA1 level in Part 2 of this TRAMAN).

Next, perform a reconnaissance survey. Observe the vegetation and decide how many men that you, as party chief, will need to cut brush. Select main control traverse stations at points appropriate for plane-table setups. Decide on the number and location of crossties or secondary traverse lines needed to provide sufficient plane-table stations. Select these points so that plane-table setups will have to be extended only a minimum distance before checking back into control.

The next step is to run the traverse lines; you should check their directions from time to time, where necessary, on long traverses. Checks could be done by astronomical methods (Part 2 of this TRAMAN), by cutoff lines, or by connecting the traverse with established points. Then run the levels, taking elevation on all traverse stations. Close, balance, and coordinate the main traverse. Then adjust the crossties into the main traverse. Balance the levels. Plot the traverse stations by coordinates on the plane-table sheets. Be sure that each sheet overlaps sufficiently. Also, be sure there is sufficient control on each sheet for orientation and for extension of setups (if necessary). Number the traverse stations with the same numbers marked on the guard stakes in the field, and show the elevations.

The plane-table work is the final big step of the fieldwork, but some transit and level work may still need to be done. The location of some details (such as street center lines or buildings) may need to be more precise than the precision obtainable with the plane table; tie in such details to the traverse by transit tape survey. For design purposes, the elevation of some points (such as the inverts of culverts, paved flumes, sewers, and tops of curbs and gutters) may need to be more precise than the precision obtainable with the plane table. Use the level to obtain such elevations. The final step in the production of the topographic map is, of course, tracing the information from the plane-table sheets onto the final drawing.

Random traversing, as previously described, is not the only way of establishing horizontal control. Grids are frequently used. One good way of identifying grid lines is to assign a letter to each line in one set and then run stationing along each line. Another method is described in the paragraphs below.

Referring to figure 9-10, suppose that this site has been chosen (through reconnaissance) for an advanced base with airstrip facilities. As you see in figure 9-10, there is a sheltered water area for a potential harbor; a strip of woodland extending back from the shore; and then a strip of clear, level country where an airstrip could be constructed.

Although topographic data for a map of this area could be obtained by one field party, it would involve extensive time and effort. Therefore, let's assume that three field parties will be used. Two of these parties are transit-level parties since they will use either transits or levels as appropriate to the work performed. The third party is a plane-table party. The plane-table party will work in the clear area and the transit-level parties will operate in the wooded and the water areas.

Basic horizontal control for both the plane-table party and the transit-level parties is the **main base line,** which is run along the edge of the wooded area as shown in figure 9-10. Topographic details in the clearing will be plotted from plane-table stations tied to the main base line. Details in the wooded area and offshore will be plotted from stations on a grid network that is tied to the main base line.

The grid network can be established in the following manner: transit-level party No. 1 runs the main base line from station 0 + 00, located at random. While running the main base line, hubs are set along the line at predetermined intervals; in this case, at every 500-foot station. Transit-level party No. 2 runs a lateral base line from 0 + 00 perpendicular to the main base line and sets hubs at every 500-foot station. From every 500-foot station on the main base line, party No. 1 will run a lateral, perpendicular to the main base line. Likewise, from each station on the lateral base line, party No. 2 will run a longitudinal, perpendicular to the lateral base line (and therefore parallel to the main base line). Hubs are driven at the intersection of each lateral and longitudinal (except in the water area). As you can see in figure 9-10, it is these lateral and longitudinal lines that form the grid net work.

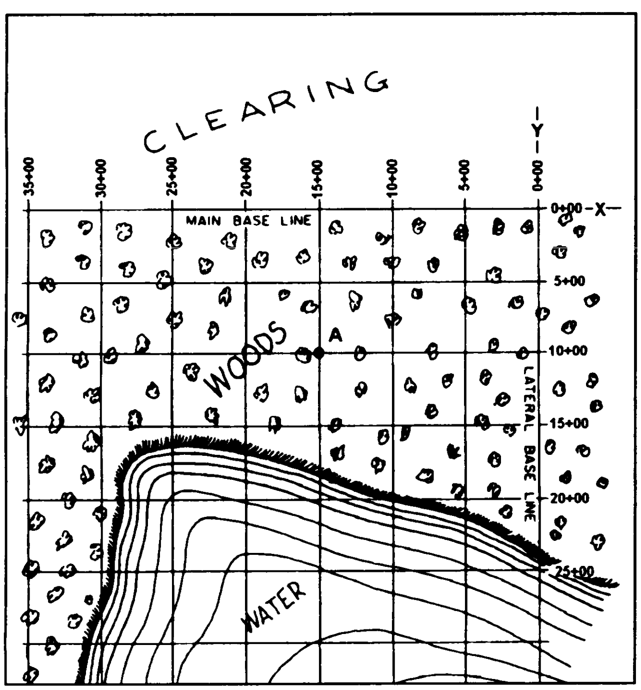

Figure 9-10.—Advanced base site.

From your previous studies you know that points within the grid can be located by coordinates, using the main base line as the *X* axis and the lateral base line as the *Y* axis; for example in terms of stations, the *X* coordinate of point A in figure 9-10 is 15 +00 and the *Y* coordinate is 10 + 00. For simplicity, these coordinates can be stated in a fractional form as 1500/1000.

With regard to vertical control for a advance base site such as we are discussing, there may be no established bench marks in the immediate area. In this case, a level net may have to be run from an established monument some distance away, perhaps several miles, to establish a bench mark in the area. If this is not possible, then a series of rod readings should be taken over a succession of high and low tides or on the high-water mark wash line along the beach. You may then use the average of these readings as a temporary vertical control datum until a more accurate datum is obtained from tide gauge readings. From a temporary bench mark at or near the beach, a line of levels can be run to station 0 + 00 on the main base line. Temporary elevations of hubs on the main base line and the lateral base line can then be determined.

Finally, the transit-level parties will shoot the detail in the vicinity of each of the intersecting grid lines.

MAP PROJECTION

Now let's discuss map and chart projection. This discussion includes the characteristics and development of various types of projections.

A paper cylinder (without ends) and a paper cone can be cut along the side and flattened out without distortion. For this reason, the two most common basic projection methods are the Mercator, in which the earth's surface is projected onto a cylinder, and the conic, in which the surface is projected onto a cone. A third method is the gnomonic method, in which the earth's surface is projected onto a plane placed tangent to a particular point. For a polar gnomonic chart, this point is one of the earth's geographical poles.

MERCATOR PROJECTION

To grasp the concept of Mercator projection, imagine the earth to be a glass sphere with a strong light at the center. Imagine, also, that the geographical meridians and parallels are inscribed as lines on the sphere at a given interval (for example, every 15 degrees). Now imagine a paper cylinder placed around the sphere, tangent to the equator, as shown in figure 9-11. The shadow images of the meridians will appear on the paper as equally spaced, parallel, vertical lines. The shadow images of the parallels will likewise appear as straight lines running perpendicular to the shadow images of the meridians. The parallels are not actually equally spaced, however; instead, the distance between adjacent parallels will progressively increase as latitude (distance north or south of the equator, the line of tangency) increases.

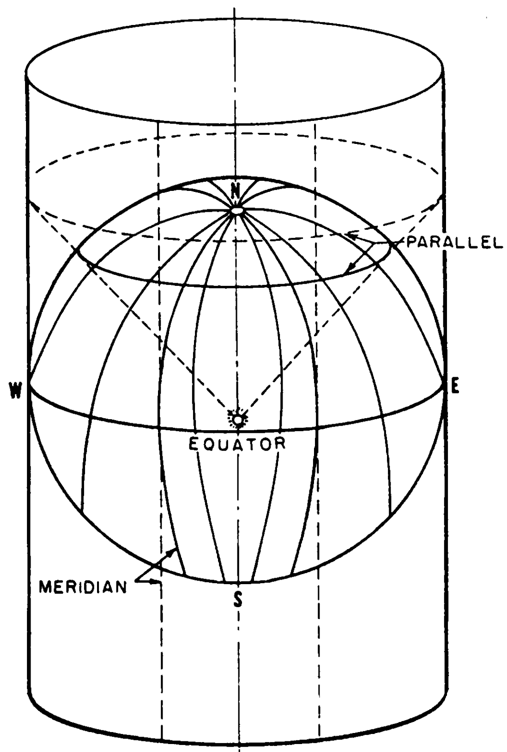

Figure 9-11l.—Mercator projection.

You can see that there are two elements of distortion here, each of which progressively increases with latitude. One is the fact that the meridians, which on the earth itself converge at each of the poles, are parallel (and therefore equidistant) for their entire length on the cylinder. The other is the fact that the parallels, which are actually equidistant on the sphere itself, become progressively farther apart as latitude increases.

These two elements produce the familiar distortion that is characteristic of a Mercator map of the world. On such a map the island of Greenland, which has an area of only about 46,740 square miles, is considerably larger in outline than the continental United States, which has an area (excluding Alaska) of about 2,973,776 square miles.

Figure 9-12 shows the meridians and parallels at 15-degree intervals of the earth's surface on a Mercator projection. Note that the parallels extend only to 80 degrees north and south. Because the cylinder has no ends, Mercator projection of regions in latitudes higher than about 80 degrees is impossible. Note, too, that although the distance along a meridian between (for example) 15°N and 30°N and between 60°N and 75°N is the same on the ground, these distances are much different on a Mercator projection. Still another characteristic to note is the fact that a meridian is perpendicular to all parallels it intersects and that all the meridians are parallel to each other.

Transverse Mercator Projection

On a Mercator projection the cylinder is placed tangent to the earth's central parallel, the equator. On

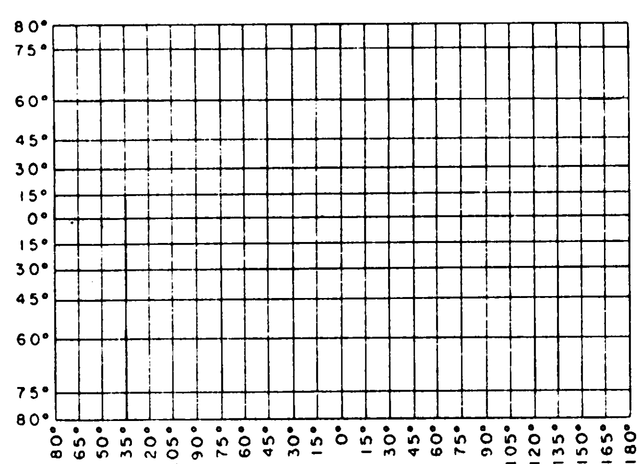

Figure 9-12.—Meridians and parallels on a Mercator projection.

a transverse Mercator projection, the cylinder is rotated 90 degrees from this position to bring it tangent to a meridian. Figure 9-13 shows the appearance of the meridians and parallels on the transverse Mercator world projection when the cylinder is flattened out. In this case, the cylinder was placed tangent to the meridian running through 0-degrees and 180-degrees longitude.

You can see that, in general, a transverse Mercator projection has less distortion than a Mercator projection does. You also can see that, unlike distortion on a Mercator projection, distortion on a transverse Mercator increases with longitude as well as with latitude away from the meridian of tangency. This is indicated by the shaded areas shown in figure 9-13. These areas are the same size on the ground. Since they lie in the same latitude, they would have the same size on a Mercator projection. On the transverse Mercator projection, however, the area in the higher longitude would be larger.

The important thing to note about the transverse Mercator, however, is the fact that in any given area the distortion is about the same in all directions. It is this fact that makes the transverse Mercator the most feasible projection for use with the military grid reference system.

A **rhumb line** is a curve on the surface of a sphere that cuts all meridians at the same angle. A mathematical navigational device, developed to plot the Mercator-projected maps, makes the rhumb line a straight line on the chart, thus preserving the same angle of bearing with respect to the intersected

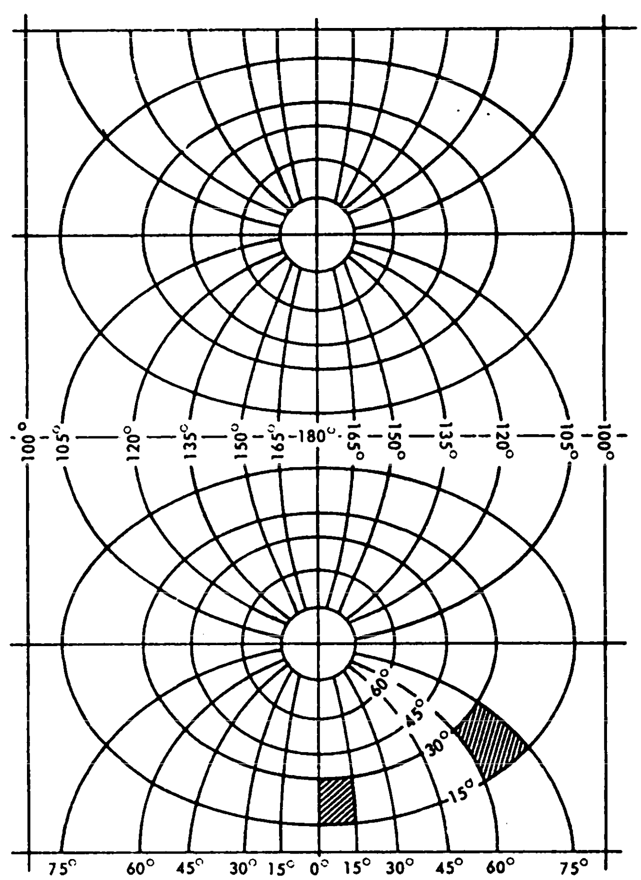

Figure 9-13.—Meridians and parallels on a transverse Mercator projection.

meridians as does the track of a vessel under a true course. On the globe the parallels become shorter toward the poles, and their length is proportionate to the cosine of latitude. In the Mercator projection the parallels are equally long. This means that any parallel is increased by 1/cos θ, or sec θ, where θ is the latitude in degrees. To have the same scale along the parallels as along the meridians, you must increase each degree of latitude by the secant of the latitude. In this mathematical transformation, the tangent cylinder concept was not employed, nor is it ever employed, in the Mercator projection. A Mercator projection table is used to plot the meridional distances. For intensive study on elements of map projection, you may refer to special publications published by the U.S. Coast and Geodetic Survey that deal with this subject.

Universal Transverse Mercator Military Grid

An extensive application of the transverse Mercator projection is in a grid reference system for military maps called the **universal transverse Mercator (UTM) military grid** system. In this system a reference plane grid, like those used in our state grid systems, is imposed on transverse Mercator projections of relatively small areas. The basic

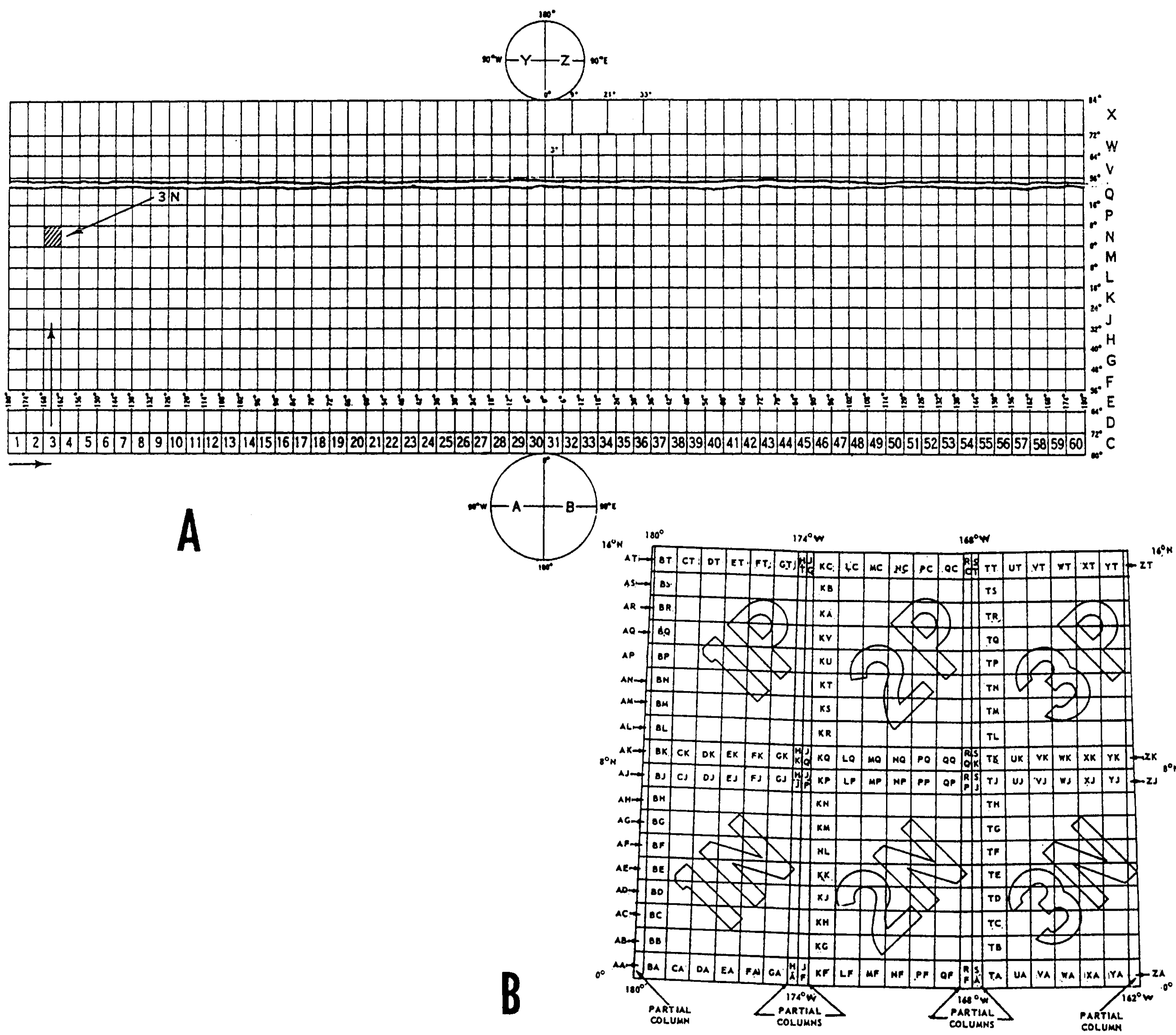

Figure 9-14.—(A) Grid zone designations of the military grid reference system; (B) 100,000-meter-square designations in the UTM military grid system,

Starting at the 180th meridian and progressing eastward by the compass, the earth's surface is divided into a succession of north-south zones, each extending for 6 degrees of longitude. These zones are numbered from 1 through 60. Between latitude 80°S and 84°N, each zone is divided into a succession of east-west rows, each containing 8 degrees of latitude, with the exception of the northernmost row, which contains 12 degrees of latitude. Rows are designated by the letters *C* through *X,* with the letters *I* and *O* omitted. The lettering system begins at the southernmost row and proceeds north. For a particular zone-row area, the designation consists of first, the zone number and next, the row letter, such as 16S, which means row S in zone 16.

The polar regions (that is, the areas above 84°N and below 80°S) have only two zones in each area. These lie on either side of the 0-degrees and 180-degrees meridian. In the North Polar region, the half of the region that contains the west longitudes is zone Y; that containing the east longitudes is zone Z. No numbers are used with these designations. Similarly, in the South Polar region, the half containing the west longitudes is zone A; that containing the east longitudes, zone B.

In the UTM Military Grid System, a particular point on the earth is further identified by the **100,000-meter square** in which it happens to lie. Each of the 6-degree longitude by 8-degree latitude zone-row areas in the system is subdivided into squares measuring 100,000 meters on each side. Each north-south column of 100,000-meter squares is identified by letter as follows. Beginning at the 180th meridian and proceeding eastward, you will find six columns of full squares in each 6-degree zone. Besides the full columns, usually partial columns also run along the zone meridians. The partial columns and full columns in the first three zones are lettered from *A* through Z, again with the letters *I* and *O* omitted. In the next time zones, the lettering systems begins over again.

Observe, for example, figure 9-14, view B. This figure shows the zone-row areas in 1N, 2N, and 3N, and 1P, 2P, and 3P. The zone meridians shown are 180°W, 174°W, 168°W, and 162°W; the zone-row parallels shown are the equator (0° latitude), 8°N, and 16°N. The first 100,000-meter-square column to the east of 180 degrees is the partial column A. Next comes six full columns: B, C, D, E, F, and G. Then comes partial column H, to the west of the zone meridian 174°W. The first column to the east of zone meridian 174°W is partial column J; then comes the full-size columns K, L, M, N, P, and Q, followed by partial column R. To the east of zone meridian 168°W, the first column is partial column S; then comes the six full columns T, U, V, W, X, and Y, and the partial column Z to the west of zone meridian 162°W.

The east-west rows of 100,000-meter squares are designated by the letters *A* through *V,* again with *I* and O omitted. For columns in the odd-numbered zones, the first row of squares north of the equator has the letter designation *A;* for columns in the even-numbered zones, the first row of squares north of the equator has the letter designation *F.* Rows above and below this row are designated alphabetically. The first row south of the equator in the odd-numbered zones, for example, has the letter designation *V,* while the first row south of the equator in the even-numbered zones has the letter designation *E.*

The complete designation for a particular 100,000-meter square consists of the number-letter, zone-row designation plus the two-letter, 100,000-meter-square designation. For example, the designation 1NBA means the first full square east of the 180th meridian and north of the equator (square BA) in zone-row 1N, as shown in figure 9-14, view B.

If you know the latitude and longitude of a certain point on the earth, you can determine the designation of the 100,000-meter square in which the point lies. Take Fort Knox, Kentucky, for example, which lies approximately at latitude **38°00'N,** longitude **86°00'W.** You will find this latitude and longitude in figure 9-15. The point lies in column 16, row S, and 100,000-meter square ES; therefore, the 100,000-meter-square designation for Fort Knox, Kentucky, is 16SES.

The location of a particular point within a 100,000-meter square is given by naming the grid coordinates of the 100-meter square (or, for more precise location, of the 10-meter square) in which the point lies. Within each zone the point of origin for measuring these coordinates is the point of intersection between the zone central meridian and the equator. A **false easting** of 500,000 meters, instead of a value of O meters, is assigned to the **central meridian** to avoid the use of west or negative east-west coordinates. For points in the earth's Southern Hemisphere, the equator is assigned a **false northing** of 10,000,000 meters to avoid the use of south or negative north-south coordinates, and northing values decrease from the equator toward the South Pole. For points in the Northern Hemisphere, the equator has a coordinate value of 0 meters, and northing values increase toward the North Pole.

This procedure results in very large coordinate values when the coordinates are referenced to the

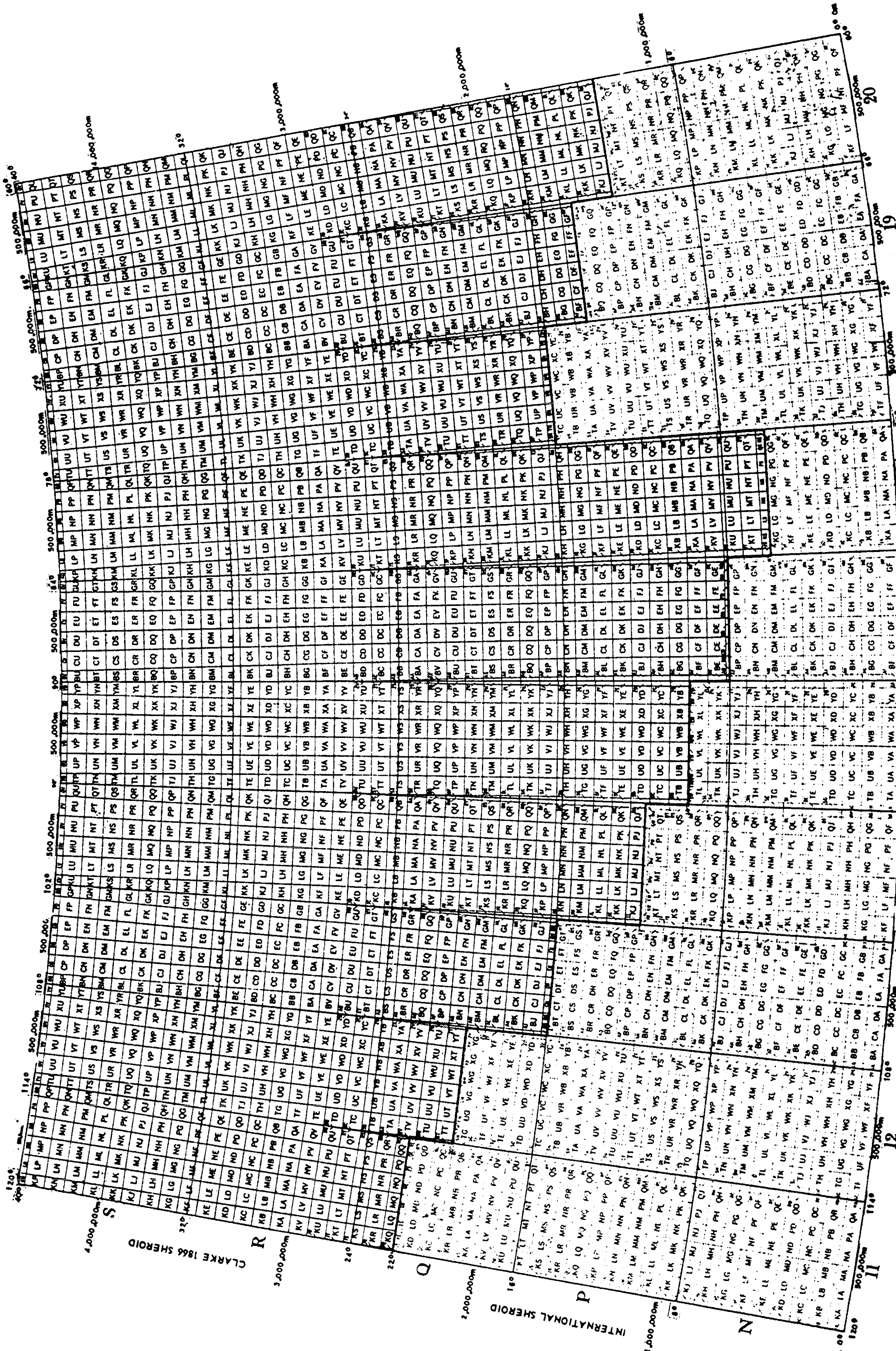

Figure 9-15.—100,000-meter-square identifications for the military grid reference system.

point of origin. For example, for the bullion depository at Fort Knox, Kentucky, the coordinates of the lo-meter square in which the depository is located are casting 590,990 meters, northing 4,193,150 meters; however, since the grid zone-row designation pins the coordinate down to a relatively small area some of the digits of the coordinates are often omitted.

Consider, for example, the part of a map shown in figure 9-16. The grid squares on this map measure 1,000 meters on each side. Note that the casting grid lines are identified by printed coordinates in which only the principal digits are shown, and of these, even the initial number 5 is in small type. The understood value of the number 589 is 589,000 meters. In setting down the coordinate for this line, even the 5 should be omitted and only the 89 written down.

Similarly, in expressing the grid location of a point, some of the digits of the coordinates are often

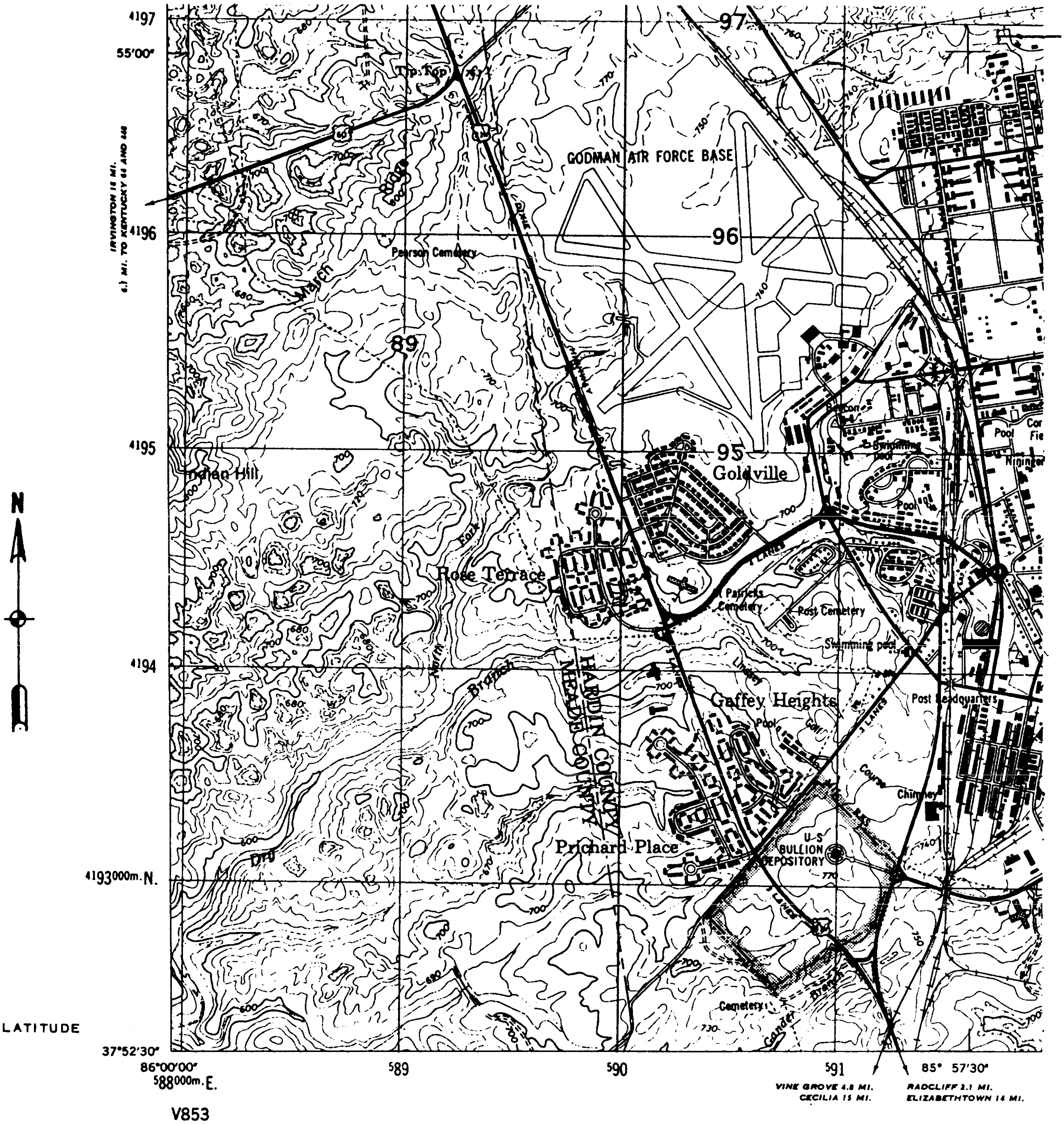

Figure 9-16.-Portion of a military map.

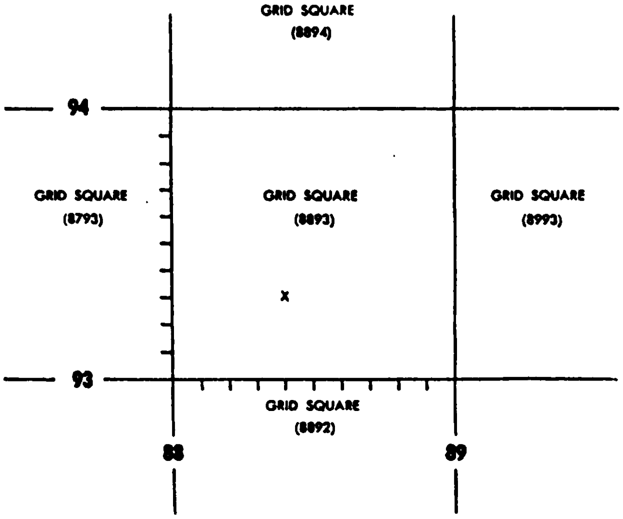

Figure 9-17.-Division of a grid square.

omitted; for example, the grid location of the bullion depository at Fort Knox may be given as 16SES90999315. This means zone-row 16S, 100,000-meter square ES, casting 9099, northing 9315. Actually, the casting is 590,990 and the northing 4,193,150.

If four digits are given in a coordinate element, the coordinates pin a point down to a particular 10-meter square. Consider figure 9-17, for example. For the point X, the two-digit coordinates 8893 would mean that the point is located somewhere within the 1,000-meter-grid square 8893. To pin the location down to a particular 100-meter square within that square, you would have to add another digit to each coordinate element. The X lies four-tenths of 1,000 meters between line 88 and line 89; therefore, the casting of the 100-meter square is 884. By the same reasoning, the northing is 933. The coordinate for the 100-meter square is therefore 884933. To pin the point down to a particular 10-meter square, you should add another pair of digits, these being determined by scale measurement on the map. It follows from all this that the coordinates previously given for the bullion at Fort Knox (909993 15) locate this building with reference to a particular lo-meter square.

Figures 9-18 and 9-19 show the marginal information usually given on a UTM grid military map. Note the reference box, which gives the grid zone-row and 100,000-meter-square designation. The

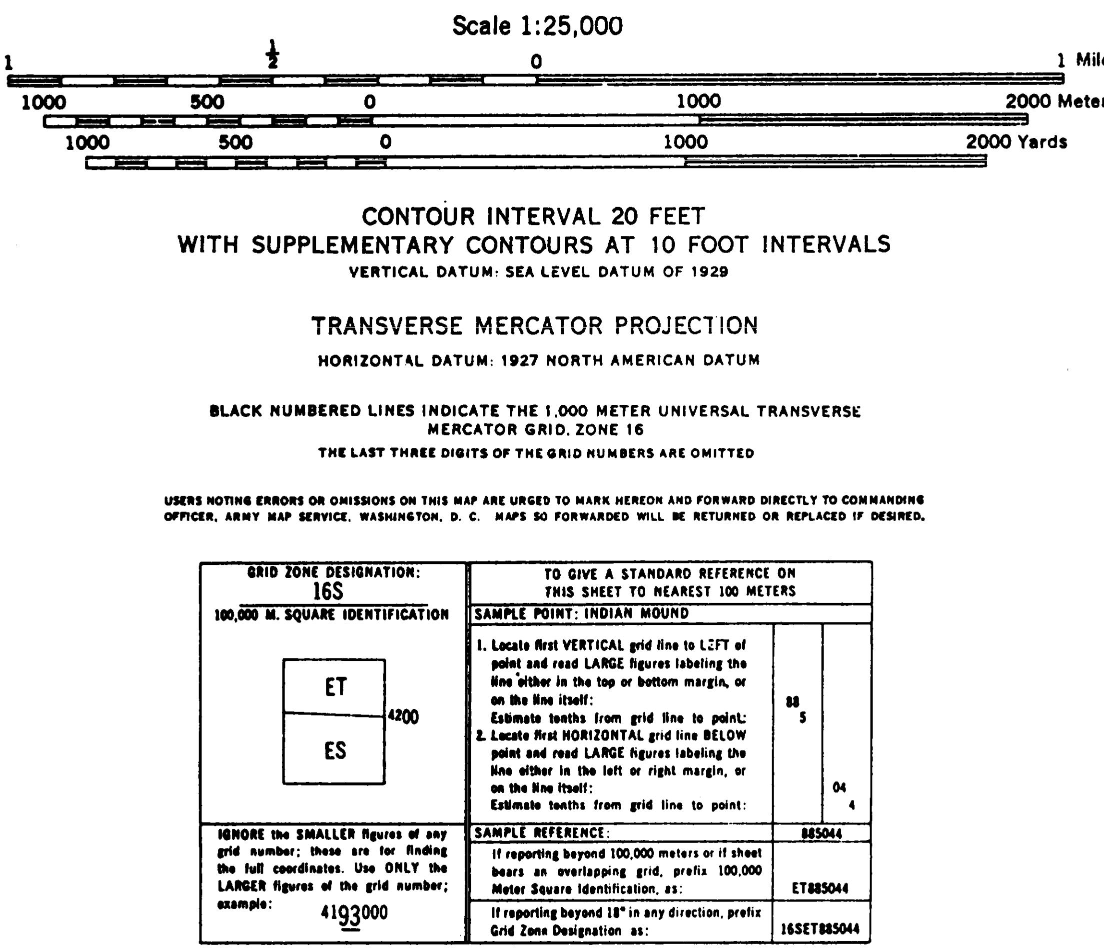

Figure 9-18.-Marginal information on a military map (1).

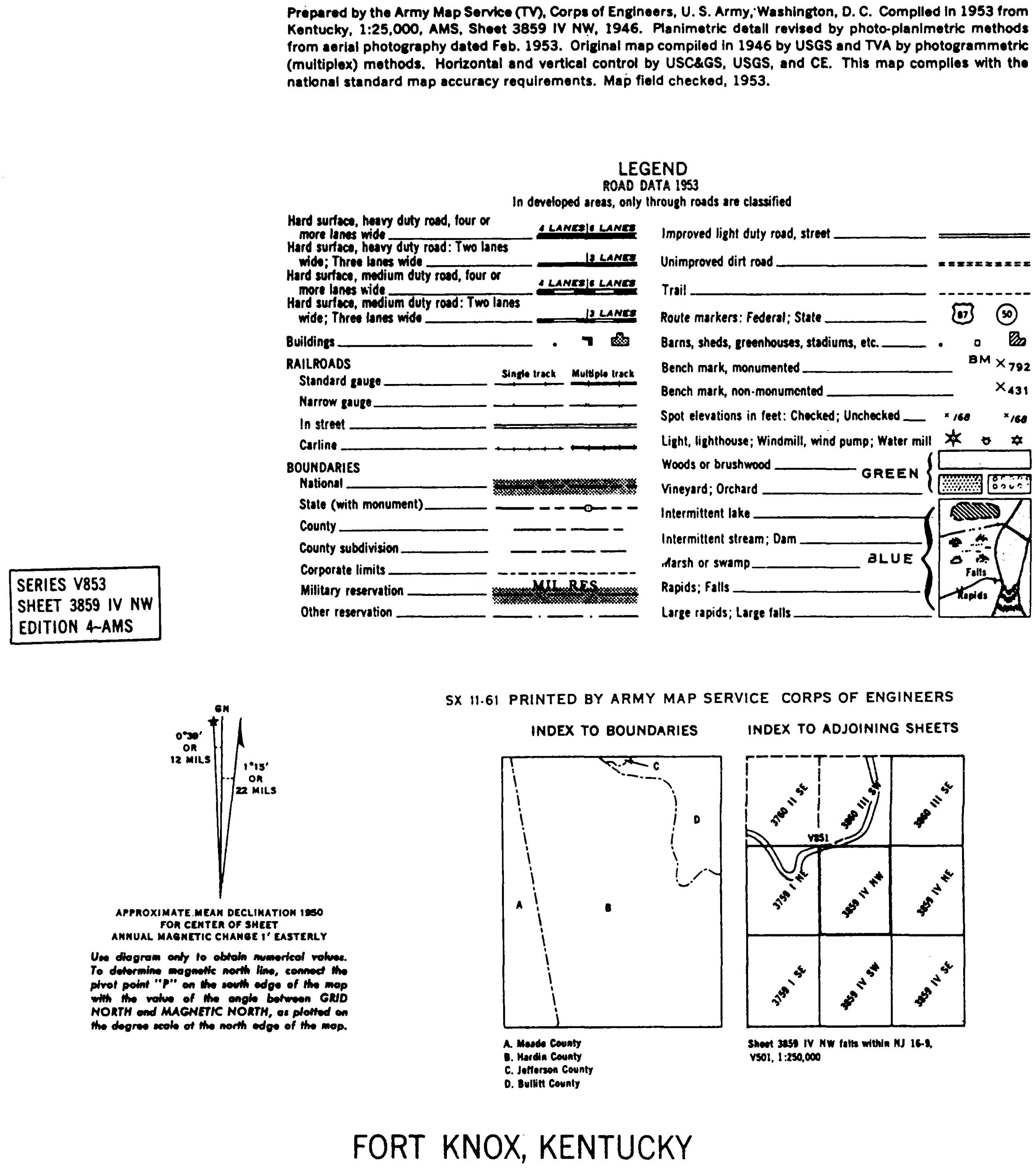

Figure 9-19.—Marginal information on a military map (2).

indicate that the map covers parts of both. Note, too, that the direction of grid north (that is, the direction of the north-south grid lines in the map) varies from that of true north by 0°39′E and from the magnetic north by 1°15′W.

CONIC PROJECTION

To grasp the concept of conic projection, again imagine the earth as a glass sphere with a light at the center. Instead of a paper cylinder, image a paper cone placed over the Northern Hemisphere tangent to a parallel, as shown in figure 9-20. The North Pole will be projected as a point at the apex of the cone. The meridians will radiate outward from the North Pole as straight lines. The parallels will appear as concentric circles, growing progressively smaller as latitude increases. When the cone is cut along a meridian and flattened out, the meridians and parallels will appear as shown in figure 9-21. In this case, the Northern Hemisphere was projected onto a cone placed tangent to the parallel at 45°N, and the cone was cut along the 180th meridian.

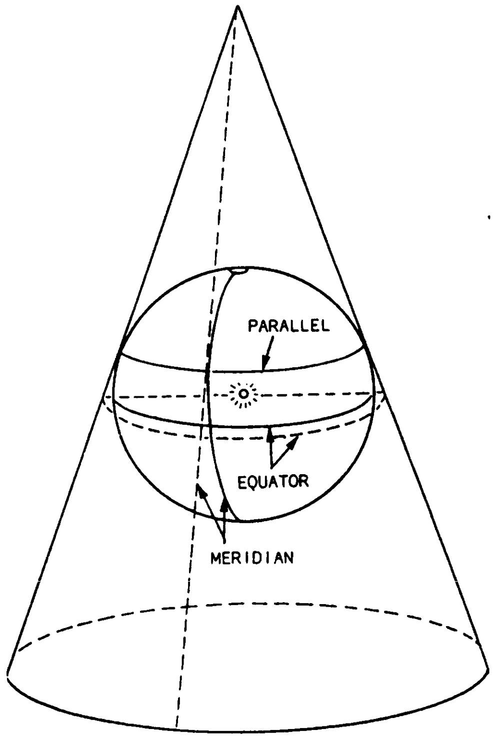

Figure 9-20.-Conic projection.

GNOMONIC PROJECTION

To grasp the concept of gnomonic projection, again imagine the lighted sphere—this time with a flat-plane paper placed tangent to the North Pole (fig. 9-22). The North Pole will project as a point from which the meridians will radiate outward as straight lines; and the parallels will appear as concentric circles, growing progressively smaller as latitude increases. The difference between this and conic

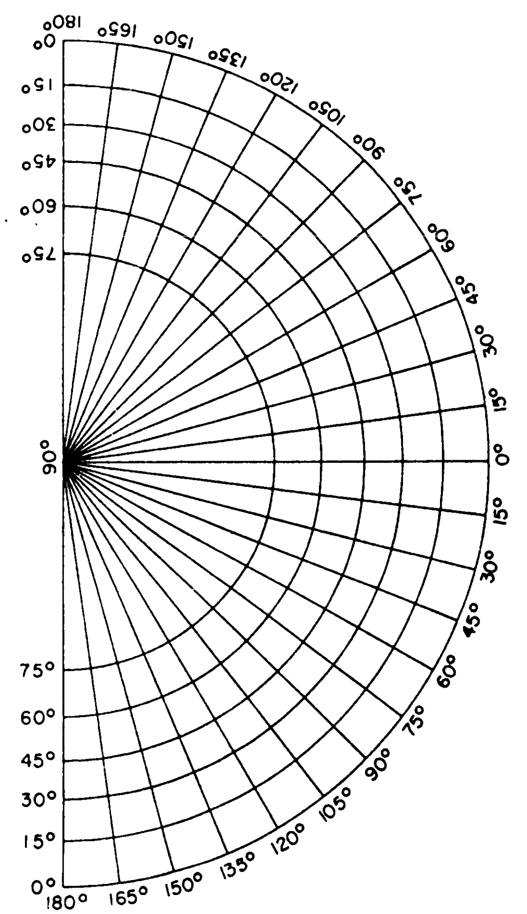

Figure 9-21.—Appearance of meridians and parallels on a conic projection.

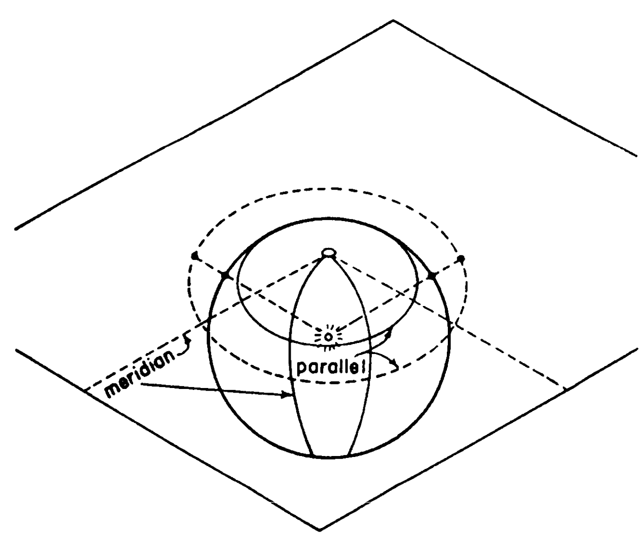

Figure 9-22.-Gnomonic projection.

projection of the polar region is the fact that in the conic projection, the cone is cut and flattened out to form the map or chart, whereas the gnomonic projection will appear as is. On the conic projection, points lying close together on either side of the meridian along which the cone is cut will be widely separated on the map. The gnomonic projection, on the other hand, will give a continuous and contiguous view of the areas. Figure 9-23 shows the appearance of meridians and parallels on a polar gnomonic projection.

CONFORMALITY

According to some authorities, to be **conformal,** a projection must possess both of the following characteristics:

1. It must be a projection on which direction is the same in all parts of the map. Obviously, for this directional conformality, the meridians (which indicate the direction of true north) must be parallel, and the parallels (which indicate true east-west direction) must be parallel to each other and perpendicular to the meridians.

2. It must be a projection on which the distance scale north and south is the same as the distance scale east and west.

Obviously, none of the projections that we have described have both of these characteristics. The only one that has the first characteristic is the Mercator. On this projection the meridians are parallel, and the parallels are parallel to each other and perpendicular to the meridians; therefore, the direction of north or east is the same anywhere on the map. With regard to the second characteristic, however, a distance of 15 degrees (for example) is longer in any part of the map north-south than a distance of 15 degrees east-west (even in the same part).

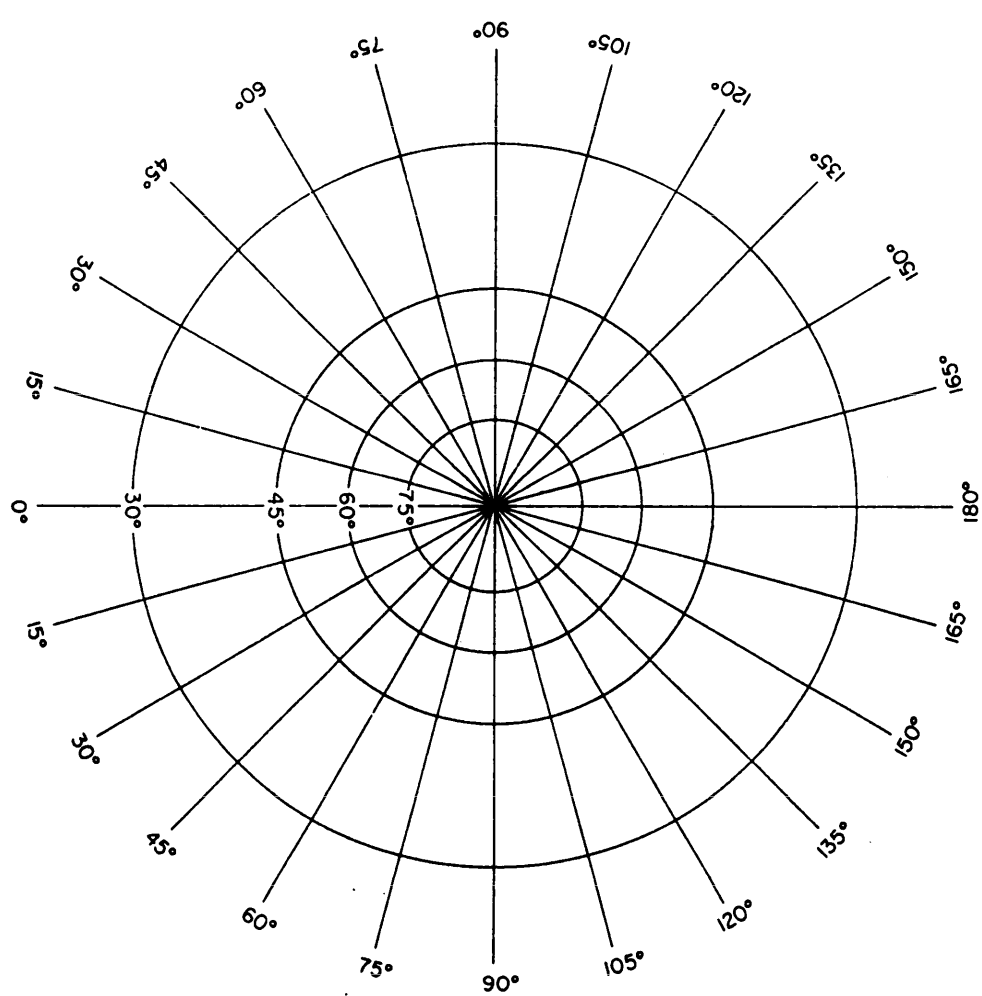

Figure 9-23.-Meridians and parallels on a polar gnomonic projection.

As for the transverse Mercator, the conic, and the gnomonic projections, a glance at the appearance of meridians and parallels on any one of these indicates not only that direction is different in different parts of the map, but that the direction of North (for example) in one part of the map may be precisely opposite to that of north in another. Let's call the two types of conformality we have mentioned **directional** conformality and **distance** conformality. Some authorities hold that directional conformality is all that is required for a conformal projection. A Mercator projection has this type of conformality, and this fact makes that type of projection highly advantageous for navigational charts. A navigator is primarily interested in determining geographical location of his ship; and the principal disadvantage of Mercator projection—the north-south compared to east-west distance distortion (which increases with latitude)–is negligible in navigational practice. This statement applies only to navigation in customary latitudes, however, since Mercator projection of the polar regions (above about 80-degrees latitude) is impossible.

For surveying and other purposes in which distance measurements must be consistent in every direction, Mercator projection presents disadvantages. To understand these, you have only to reflect on the fact that no distance scale could be consistently applied to all parts of a Mercator projection, which means that no square grid system could be superimposed on a Mercator projection; however, the transverse Mercator projection, as it is used in conjunction with the UTM military grid, provides relatively small-area maps that are virtually conformal, both direction-wise and distance-wise.

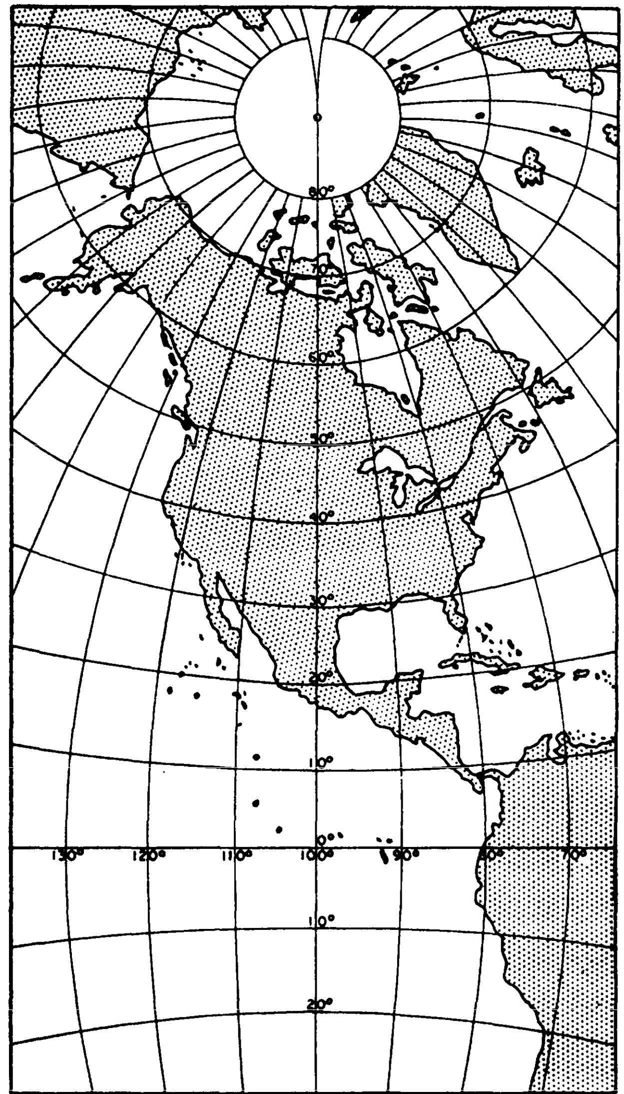

Figure 9-24.—Polyconic projection of North America.

POLYCONIC PROJECTION

In **polyconic projection** a near approach to direction conformality is obtained in relatively small-area maps by projecting the area in question onto more than one cone. A central meridian on the map is straight; all the others are slightly curved and not quite parallel. Similarly, the parallels are slightly curved and not quite parallel; therefore, they are not precisely perpendicular to the meridians. An example of a polyconic map projection is shown in figure 9-24.

Polyconic projection is extensively used for the **quadrangle** maps (familiarly called **quad sheets)** of areas of the United States published by the Geological Survey. For most of the built-up areas of the States, these maps are available on a scale of 1:24,000, showing areas extending for 7°30' of latitude and longitude. An **index map** is available, which gives you the quadrangle divisions and the name of the map that covers a particular area.

That polyconic projection is not conformal distance-wise is indicated by the fact that one of these quad sheets, though it shows an area that is square on the ground, is oblong rather than square. The vertical or latitudinal length of the map is always greater than the horizontal or longitudinal length. The reason is that latitude is measured along a meridian, which is always a great circle, while longitude is measured along a parallel; and every parallel other than the equator is less than a great circle.

An understanding of the concept of the great circle is essential to a thorough understanding of map and

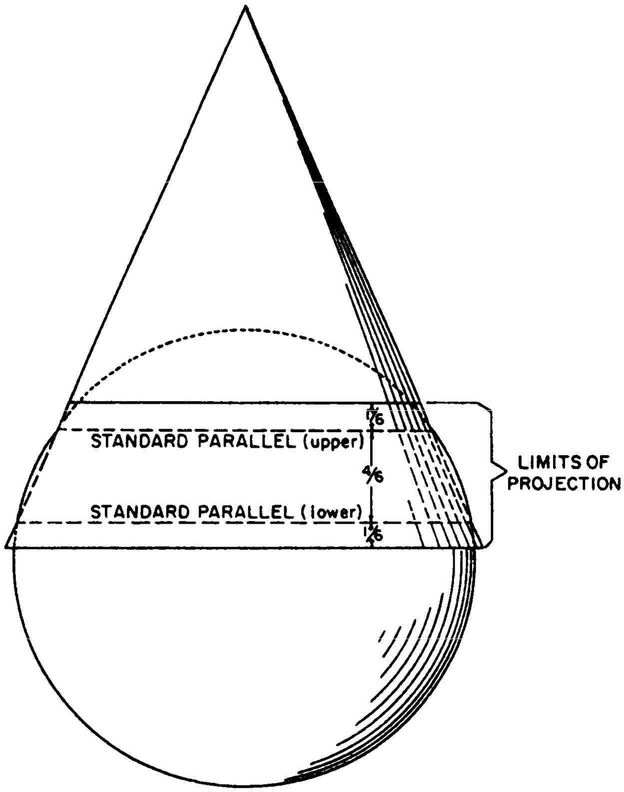

Figure 9-25.-Lambert conformal conic projection.

chart projection. A great circle is any line on the earth's surface (not necessarily a meridian or the equator) that lies in a plane that passes through the earth's center. Any meridian lies in such a plane; so does the equator. But any parallel other than the equator lies in a plane that does not pass through the earth's center; therefore, no parallel other than the equator is a great circle.

Now, 1 minute of arc measured **along a great circle** is equal to 1 nautical mile (6076.115 ft) on the ground. But 1 minute of arc measured along a small circle amounts to less than 1 nautical mile on the ground. Therefore, a minute of latitude always represents a nautical mile on the ground, the reason being that latitude is measured along a meridian and every meridian is a great circle. A minute of longitude at the equator represents a nautical mile on the ground because, in this case, the longitude is measured along the equator, the only parallel that is a great circle. But a minute of longitude in any other latitude represents less than a nautical mile on the ground; and the higher the latitude, the greater the discrepancy.

LAMBERT CONFORMAL CONIC PROJECTION

The **Lambert conformal conic projection** attains such a near approach to both directional and distance conformality as to justify its being called a conformal projection. It is conic, rather than polyconic, because only a single cone is used, as shown in figure 9-25. Instead of being considered tangent to the earth's surface, however, the cone is considered as penetrating the earth along one **standard parallel** and emerging along another. Direction is the same at any point on the map, and the distance scale at a particular point is the same in all

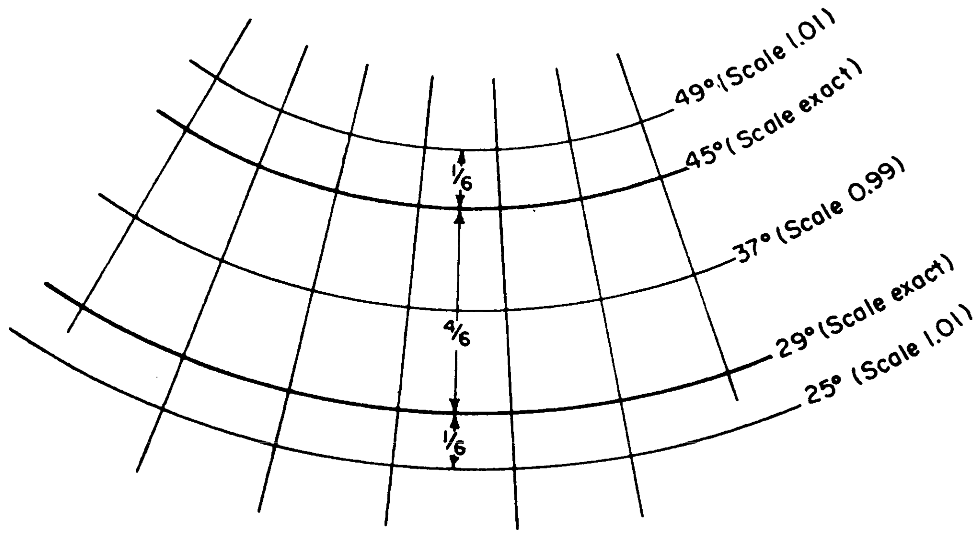

Figure 9-26.-distortion of the Lambert conformal conic projection with the standard parallels at 29 degrees and 45 degrees.

directions. However, the distance scale that applies to the whole map is exact only at the standard parallels, as shown in figure 9-26. Between the parallels the scale is a little too small; beyond them, it is a little too large. The discrepancy is small enough to be ignored in work of ordinary precision or less. For work of higher precision, there are correction factors that may be applied.

The Lambert conformal conic projection is the base for the state coordinate systems devised by the Coast and Geodetic Survey for zones of limited north-south dimension and indefinite east-west dimension. For zones whose greater dimension is north-south, the Coast and Geodetic Survey uses the transverse Mercator projection.

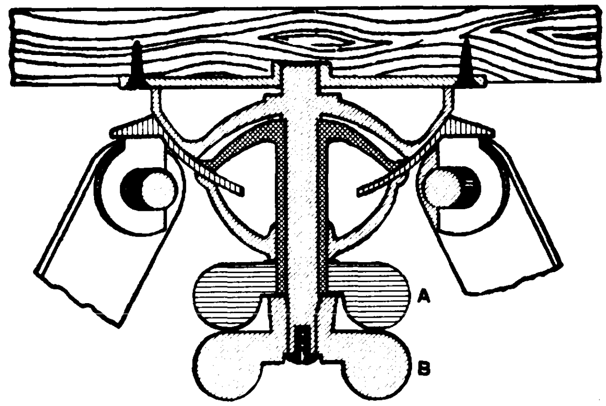

Figure 9-27.-Cross section of a plane-table tripod head.

QUESTIONS

Q1. Which one of the wingnuts, labeled A and B, in figure 9-27 permits a leveled plane table to be rotated in azimuth?

Q2. Assume you are using three-point resection to plot the location of point P and the triangle of error is inside the main triangle formed by the three known points. Where in relation to the triangle of error is point P located?

Q3. What point-location method can you use to run a traverse using a plane table?

Q4. Compute the missing column entries for point 5 in figure 9-8.

Q5. Why is transverse Mercator projection the preferred projection method for use with the military grid reference system ?

Q6. Refer to figure 9-14. What is the complete designation for the first full square east of meridian 168°W and south of the equator?

Q7. Measured along any meridian, what is the approximate distance in statute miles between 16°30′N latitude and 0°30′S latitude ?

r again to figures 8.5 and 8.6, you will

If you will ref